Monte Carlo Integration and Principal Component Analysis of Pan-Spectral OSSE Data

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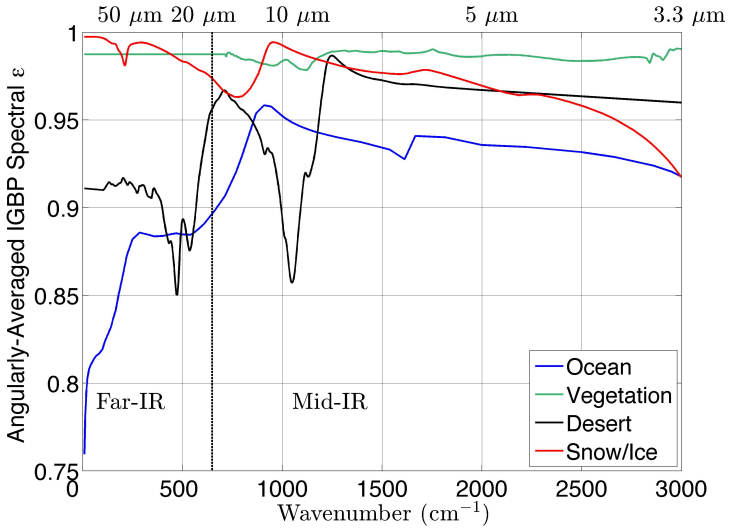
Outline

- Research Highlights.
- Overview of tasks proposed for NASA Spectral Sciences.
- OSSE Speed-Up with Simple Sampling Strategy.
- Principal Component Analysis Methods.
- Discussion.

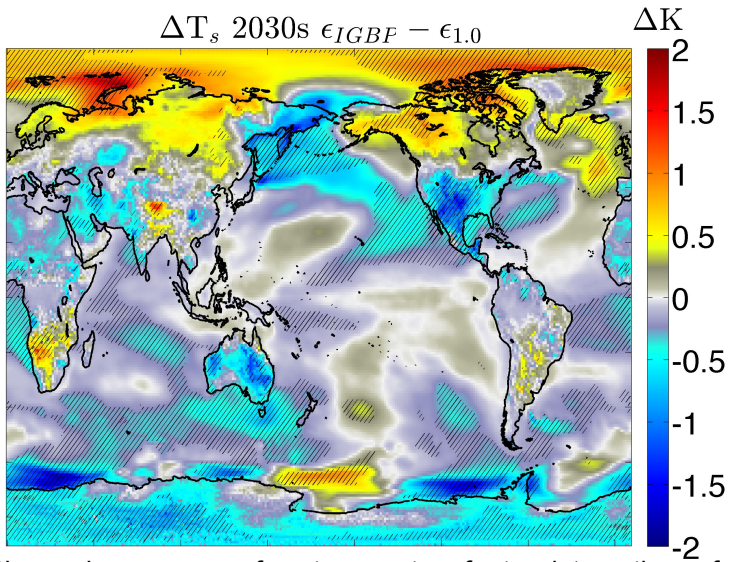
Highlights: Far-Infrared Surface Emissivity and Climate

(PI: W.D. Collins)

- Calculations based on the published literature lead to systematically lower far-infrared surface emissivity for non-frozen surfaces as compared to frozen surfaces.
- There is a potential for a positive feedback at high latitudes and high altitudes where the far-infrared is relatively transparent, but observations, such as from CLARREO are needed to characterize this effect.



Calculations of spectral surface emissivity based on published indices of refraction for several IGBP surface types.



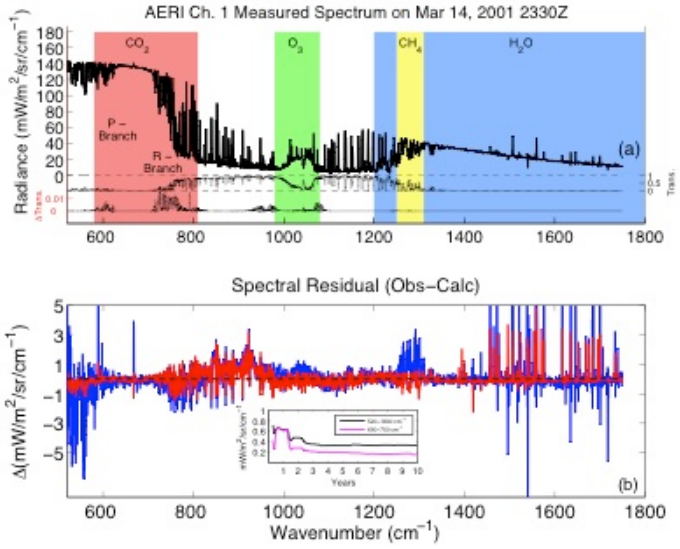
Change in average surface temperature for two integrations of CESM RCP8.5, where one integration was modified to include realistic surface emissivity, leading to a much warmer Arctic.

Feldman, D.R., W.D. Collins, R. Pincus, X.L. Huang, X.H. Chen (2014) Far-Infrared Surface Emissivity in Climate, *Proceedings of the National Academy of Sciences of the United States of America*, **111**(46), doi: http://dx.doi.org/10.1073/pnas.1413640111.

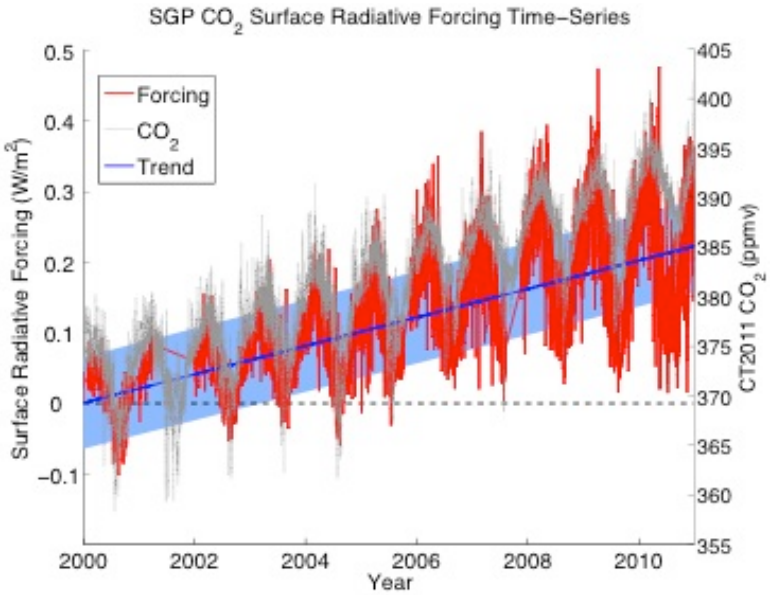
Highlights: First Direct Observation of CO_2's Greenhouse Effect at the Earth's Surface

(PI: M.S. Torn)

- Long-duration, absolutely-calibrated spectroscopic measurements at two ARM sites provide the first ever observation and quantification of the increase in CO_2's greenhouse effect over a decade of observations.
- This study derived forcing from direct observations, highlighting the high-profile science that is possible with climate monitoring measurements.



Sample spectroscopic observation from the AERI instrument at the Southern Great Plains site and residual spectra.



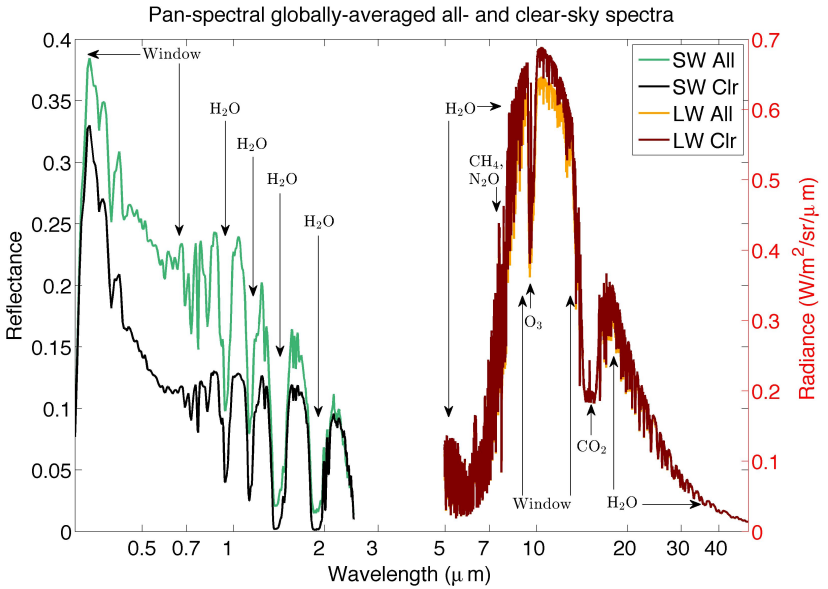
Time-series of the CO_2 concentration in the lowest 2 km and the forcing derived from AERI observations

Feldman, D.R., W.D. Collins, P.J. Gero, M.S. Torn, E.J. Mlawer, T.R. Shippert (2015) Observational determination of surface radiative forcing by CO_2 from 2000 to 2010, *Nature*, doi: http://dx.doi.org/10.1038/nature14240.

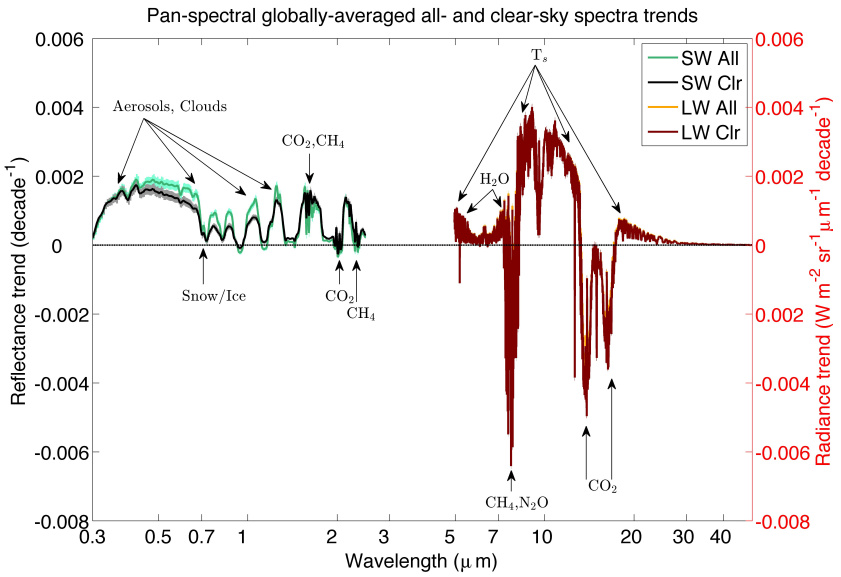
Highlights: Pan-Spectral OSSEs

(PI: D.R. Feldman)

- Summary of simulations of both the shortwave reflectance and longwave radiance clear-sky and all-sky CLARREO (OSSE), indicating the complementarity of the signals.



Globally-averaged shortwave and longwave clear- and all-sky spectra from the CLARREO OSSE.

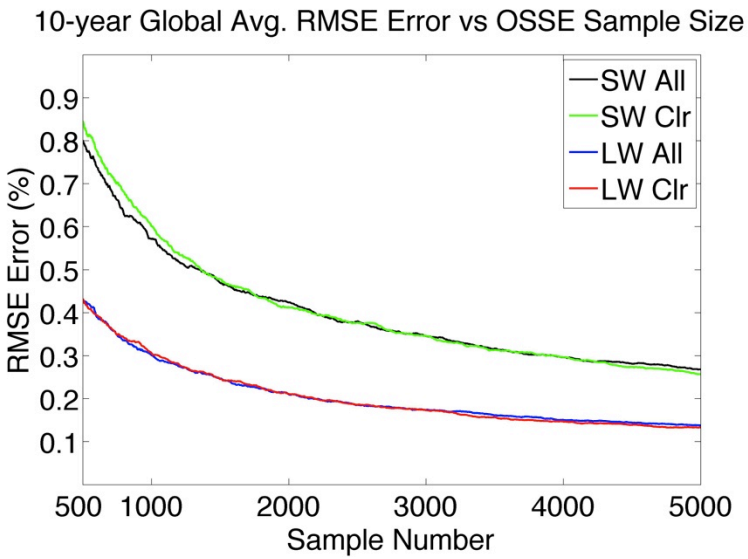


Globally-averaged shortwave and longwave clear- and all-sky spectral trends from the CLARREO OSSE.

Feldman, D.R., W.D. Collins, J.L. Paige (2014) Pan-Spectral Observing System Simulation Experiments of Shortwave Reflectance and Longwave Radiance for Climate Model Evaluation, *Geoscientific Model Development Discussions*, **7**(3), 3647-3670, doi: http://dx.doi.org/10.5194/gmdd-7-3647-2014.

Monte Carlo Sampling

- We compare averages of random sampling of OSSE grid-cells vs calculations based on all grid cells.
- Sampling results indicate that acceptable radiometric error is incurred with 1000x fewer calculations are needed for global 10-year averages, 60x fewer calculations for regional averages.



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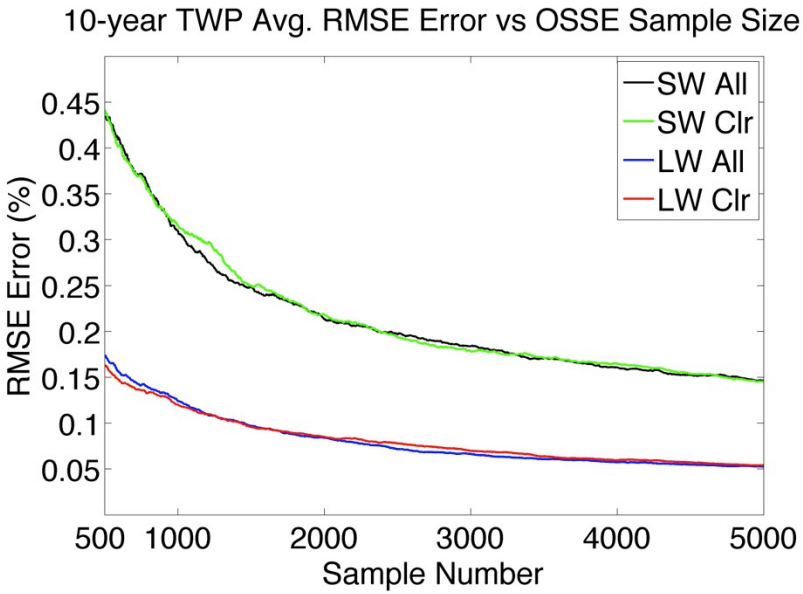

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Principal Component Analysis

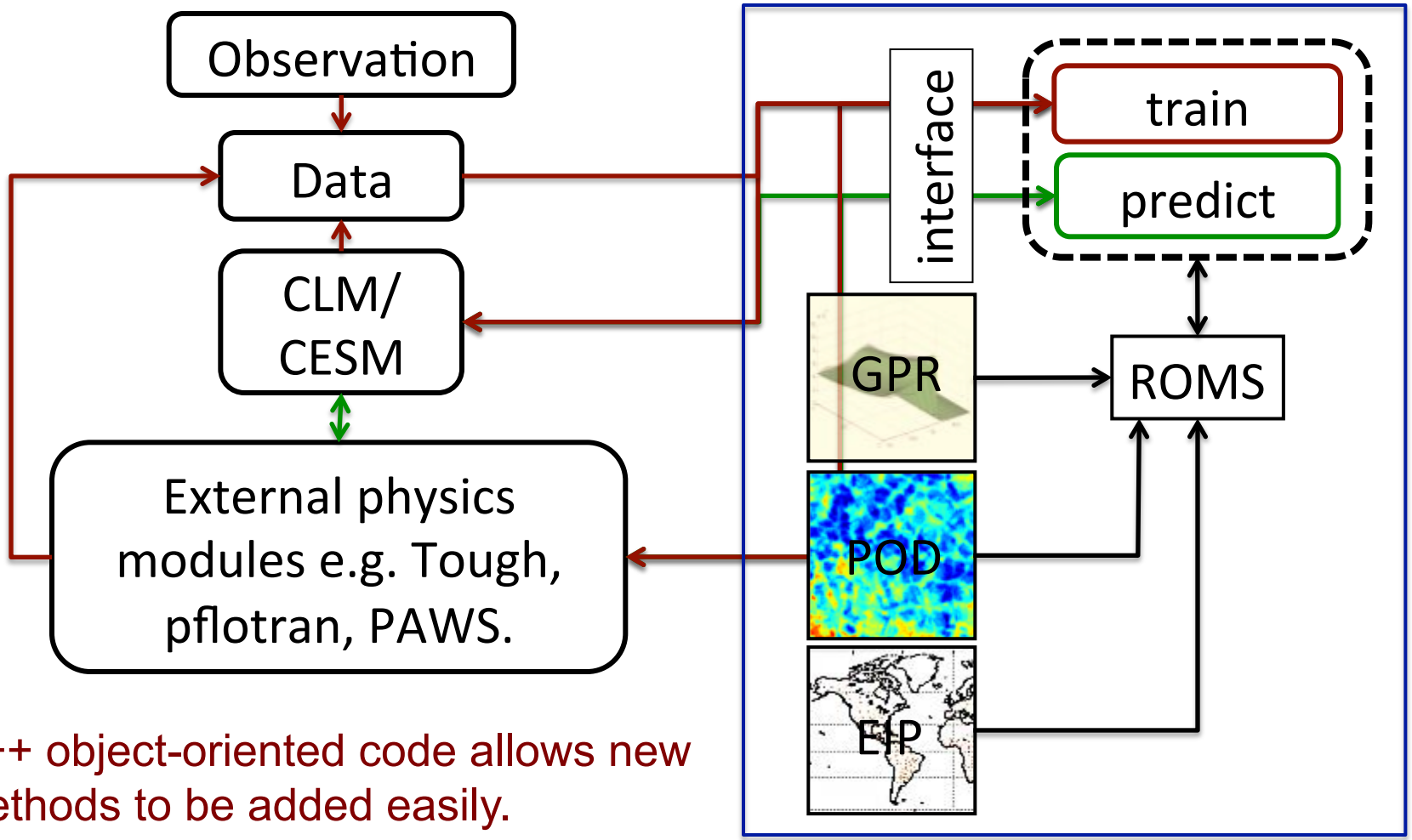
- We seek to use signal analysis methods are based on principal component scores rather than spectral measurements themselves to take full advantage of spectral correlations.

- Publications by Roberts have shown value of SW PCA, publications by Huang showed value of LW PCA … what about SW+LW?

- Some considerations for pan-spectral PC:
  - Units differ in each band.
  - Number of channels differs in each band.
  - SW has a polar terminator, LW does not.

- Mechanically, pan-spectral PCA requires unitless data, normalize by sample variance, and evenly weight variance contributions from SW and LW.

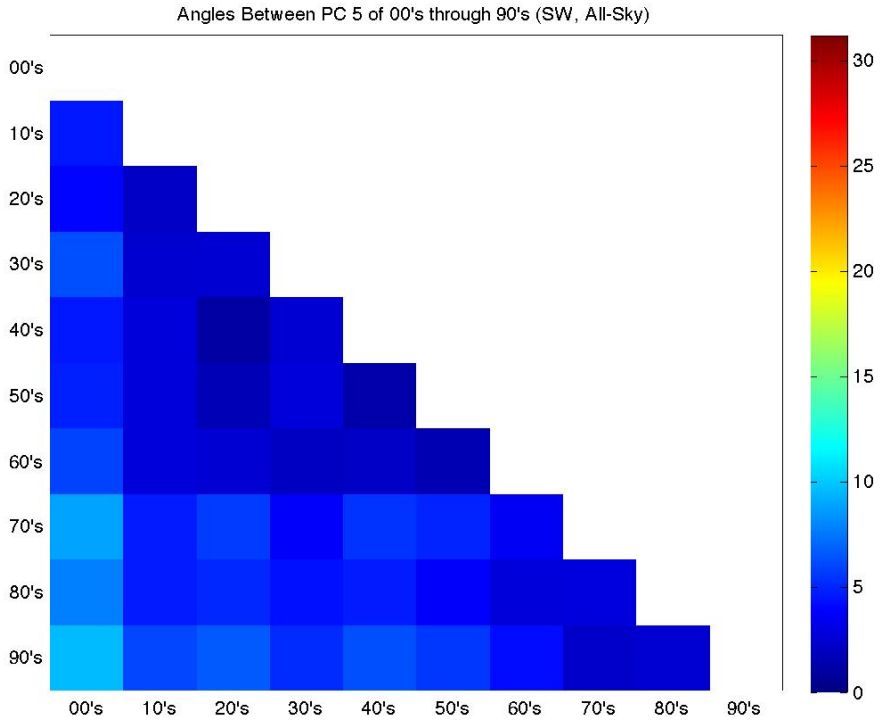
Parallel Reduced Order Models for Earth Systems (pROME)

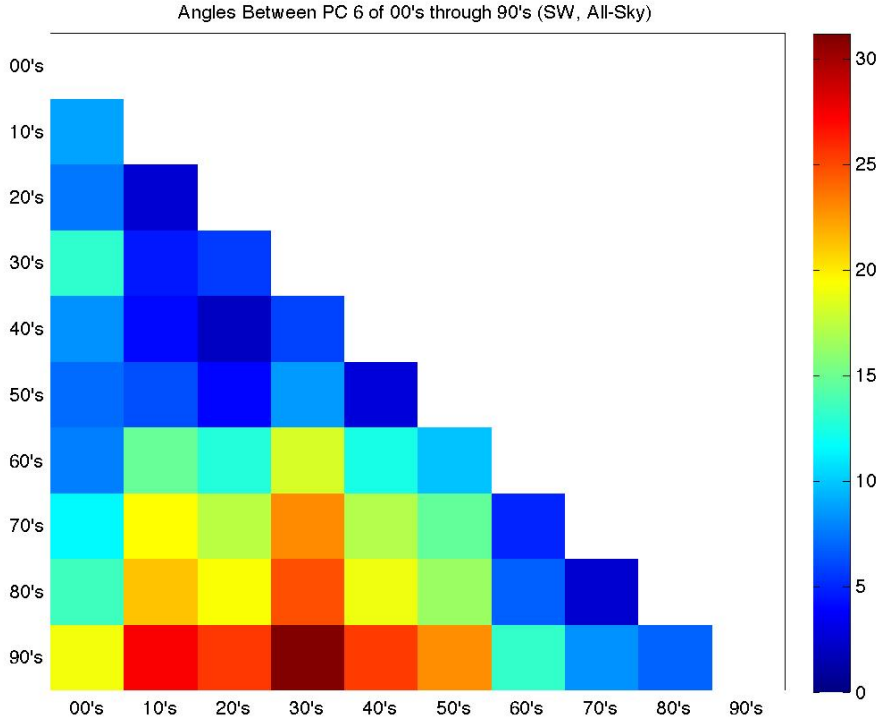


C++ object-oriented code allows new methods to be added easily.

New Modes of Variability: SW

Critical first test is to investigate whether new modes of variability arise under climate change conditions. Does variability described by present-day PCs persist? In OSSEs, yes.





New Modes of Variability: LW

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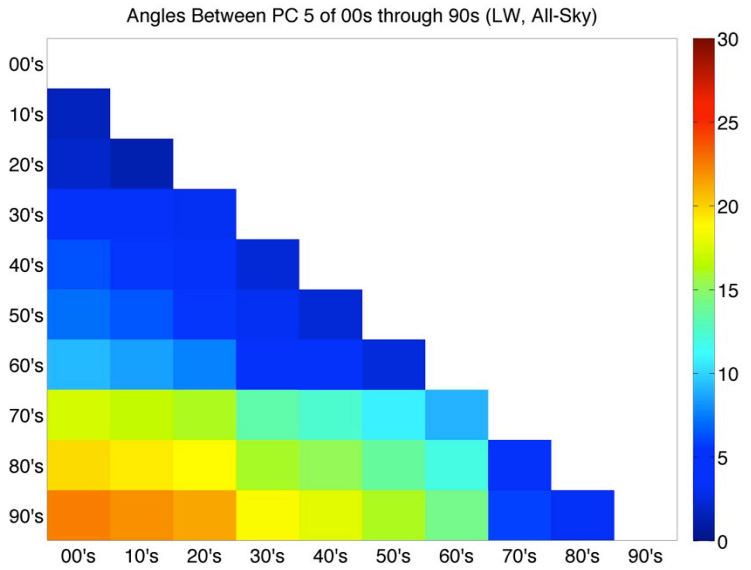
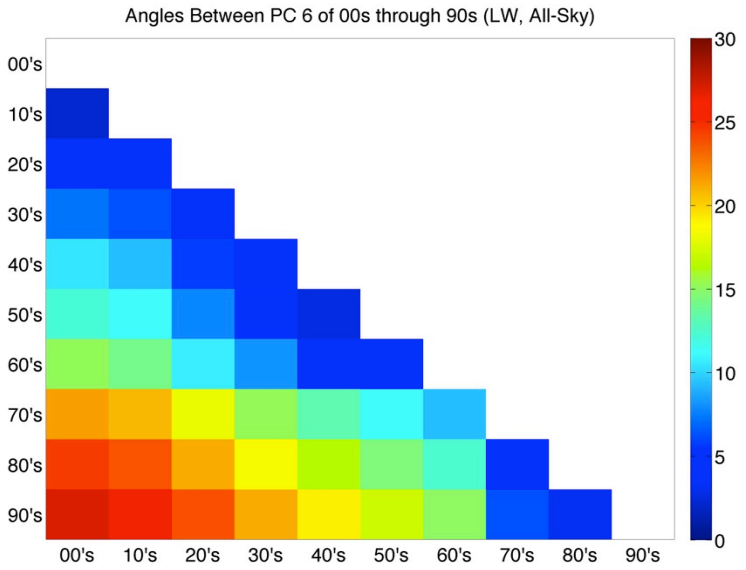
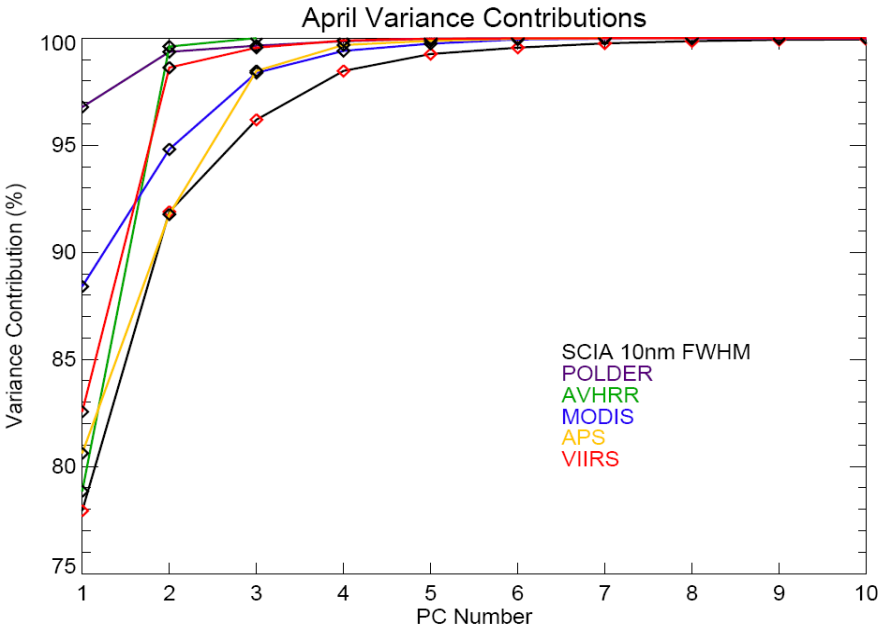




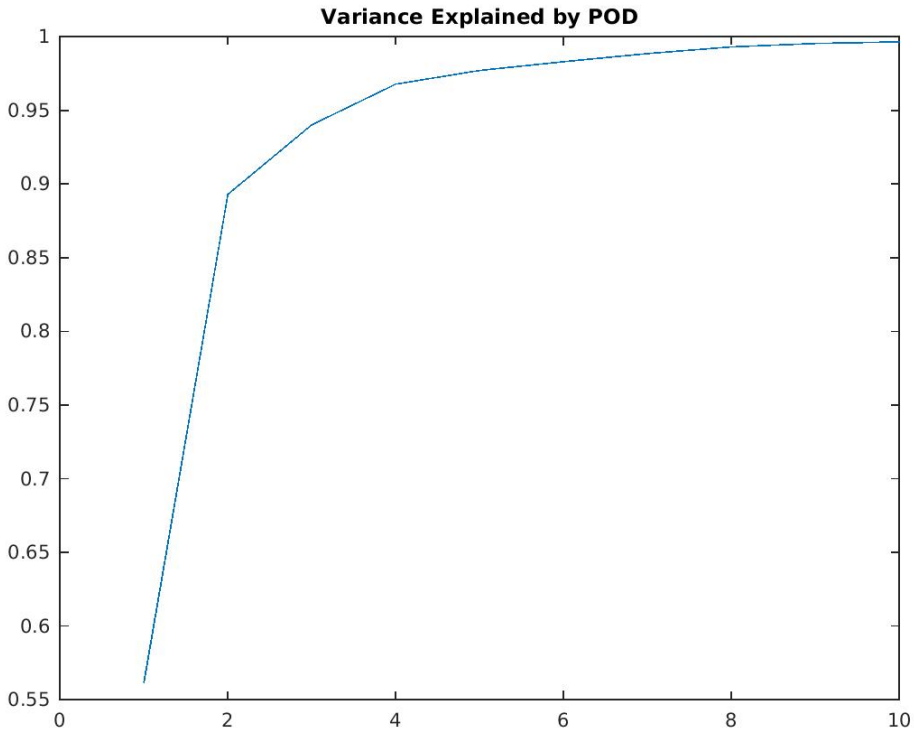
Variance Explained

The variance contribution of the first 10 PCs indicate greater importance of higher PCs as compared to SW PCA.

SW only (from Y. Roberts)

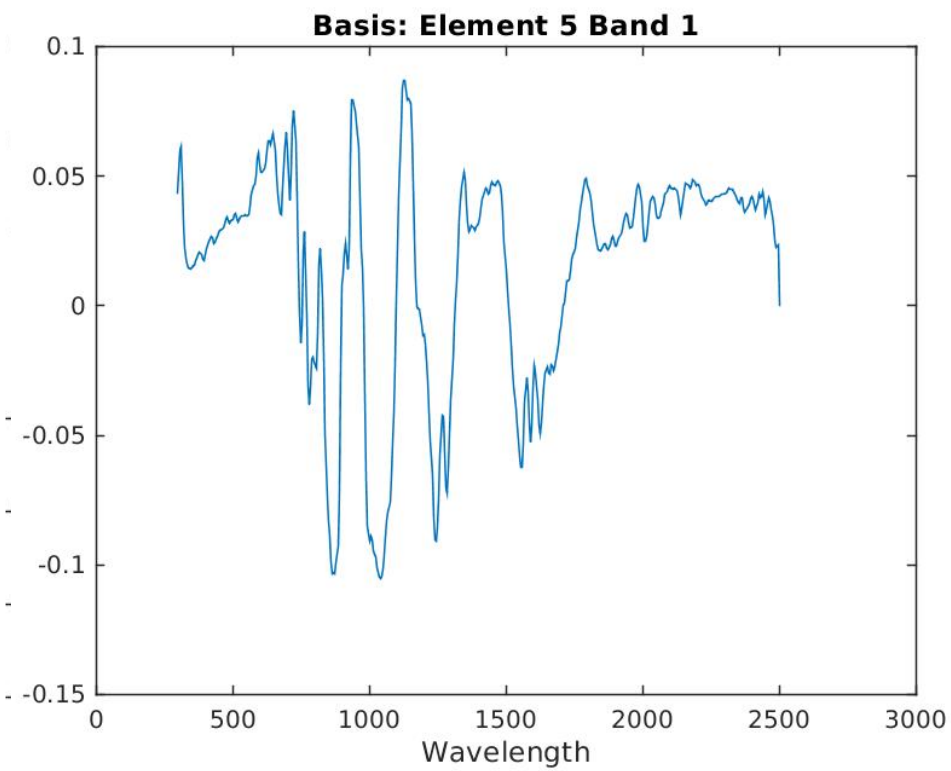


SW+LW

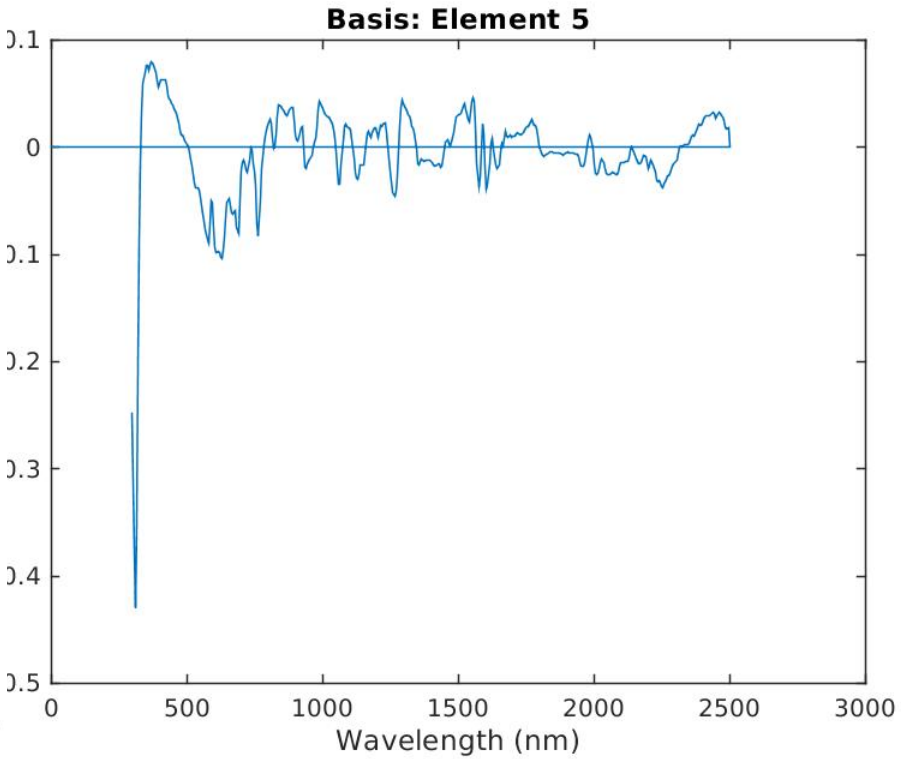


OSSE SW Reflectance PCs

SW+LW

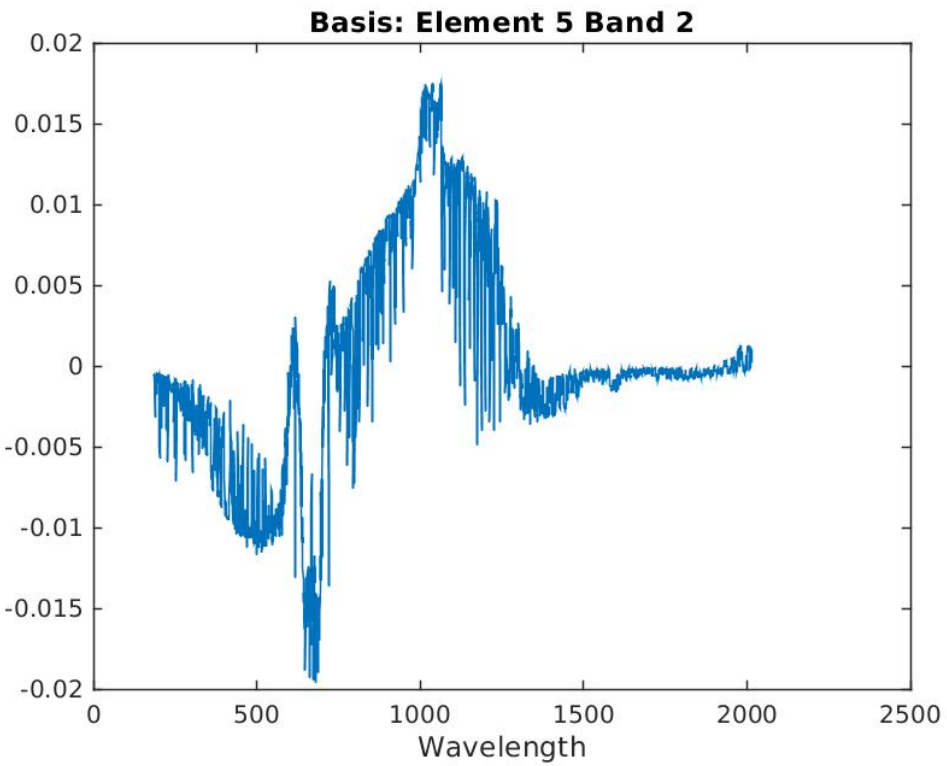


SW

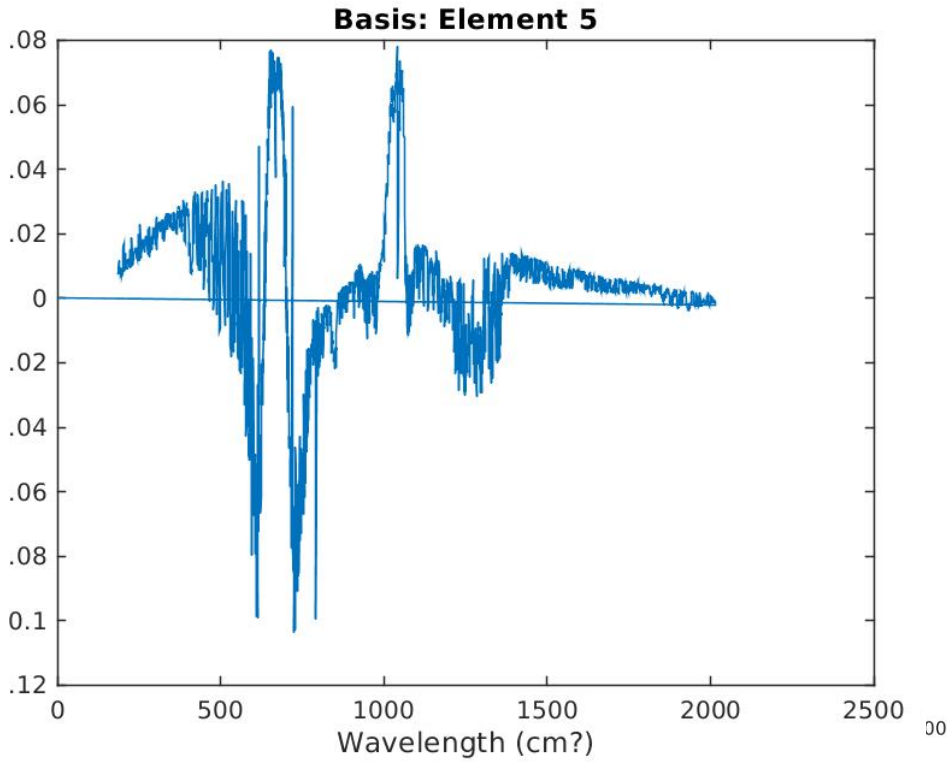


OSSE LW Radiance Separate PCs

SW+LW



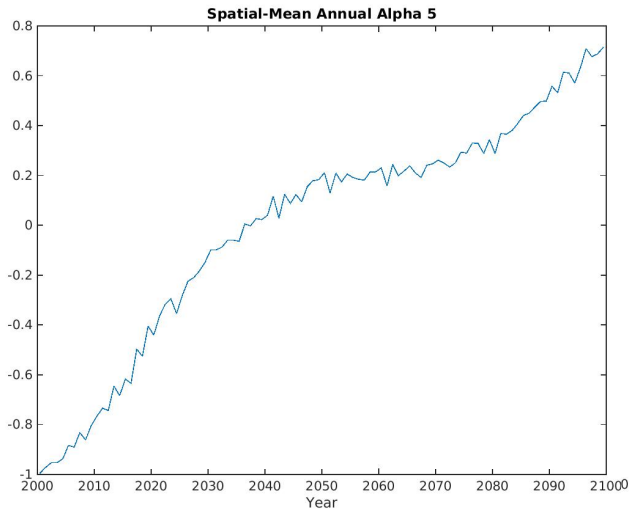
LW



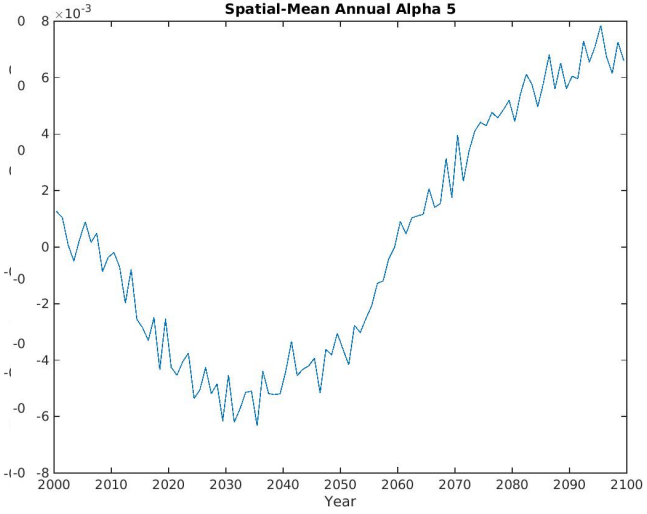
Well-Behaved PC Time-Series

Time-Series of Pan-Spectral PC scores indicate secular trends, and pan-spectral PC2 and PC4 prominently contain feature of anthropogenic sulfate aerosol emissions. Analysis of a single PC time-series is straightforward, but consideration needed for all PC time-series.

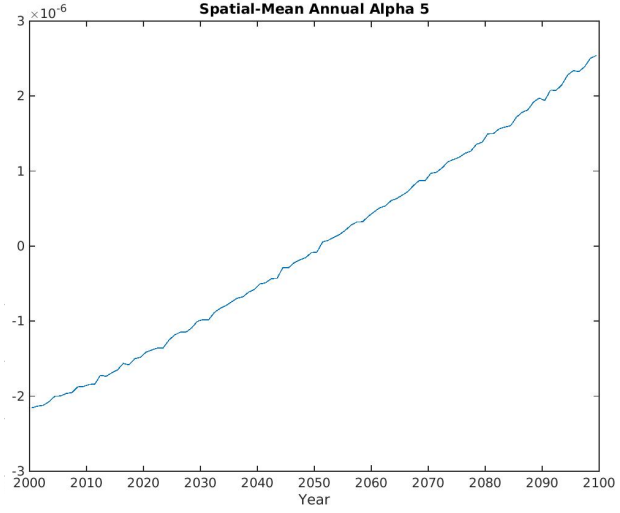
SW+LW



SW



LW



Summary

- Research highlights show:
  - The immediate value of CLARREO in making far-IR measurements.
  - How calibrated measurements enable detailed model testing.
  - The complementarity of SW+LW spectra.
- Simple MC sampling can reduce OSSE computational burden by 1000x.
- Within the existing OSSE, new modes of variability are not emerging.
- PCA leads to well-behaved time-series that are amenable to detection time-series analysis.

Acknowledgements:
This research was supported by NASA grants NNX08AT80G, NAS2-03144, NNX10AK27G and NNX11AE65G. NERSC and NASA High-End Computing grants provided computational resources produce the simulations.

Future Directions

- OSSE demonstration with MC sampling on CMOR-ized data.
  - Investigation into optimal sampling strategies.
  - Exploration into PPE OSSEs.
- OSSEs to compare spectral fingerprinting retrievals vs traditional retrievals.
  - What are the nonlinearities in multi-decadal length SW+LW fingerprints?
- Should OSSE infrastructure consider CLARREO Pathfinder (e.g., ISS orbit)?